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Claims

[c1] A method of making a trench capacitor comprising:
forming a trench in a substrate;
widening said trench;
forming a sacrificial collar on sidewalls of said widened trench;
vertically deepening said trench to extend below said sacrificial collar; and
forming a capacitor in said trench below said sacrificial collar.

[c2] The method of Claim 1 further comprising forming a pad stack on said substrate, forming a hard mask over said pad stack, and patterning said hard mask and said pad stack to form an opening therein, wherein said trench is formed by etching said substrate through said opening.

[c3] The method of claim 2 further comprising selectively widening sidewalls of said opening in said pad stack such that said hard mask overhangs sidewalls of said opening in said pad stack.

[c4] The method of Claim 1 wherein said trench is formed by anisotropic etching.

[c5] The method of Claim 1 wherein said trench is widened by isotropic etching using a chemistry selected from the group consisting of dry plasma process, wet silicon etch process, and an HNO_3/HF mixture.

[c6] The method of Claim 1 wherein said trench is widened by anisotropic etching using a chemistry selected from the group consisting of wet alkaline chemistry and NH_4OH.

[c7] The method of Claim 1 wherein said trench is deepened by anisotropic etching.

[c8] The method of Claim 1 wherein said sacrificial collar includes an underlayer of oxide and a top layer of nitride.

[c9] The method of Claim 1 wherein said sacrificial collar comprises a layer of nitride.

[c10] A method of providing a trench capacitor on a semiconductor substrate, comprising:
forming a pad stack on a semiconductor substrate;
forming a hard mask over said pad stack;
patterning said hard mask and said pad stack to form an opening;
vertically etching said substrate in said opening to form a trench;

horizontally widening sidewalls of said trench to widen an opening of said trench;
forming a sacrificial collar on said widened sidewalls;
vertically deepening said trench to create a lower portion extending below said sacrificial collar; and
forming a capacitor in said lower portion.

[c11] The method of Claim 10 wherein said pad stack comprises a pad nitride layer overlying a pad stop layer including an oxide.

[c12] The method of Claim 10 wherein said hard mask comprises an oxide layer selected from the group consisting of a tetraethylorthosilicate (TEOS) deposited oxide layer and a borosilicate glass (BSG) deposited oxide layer.

[c13] The method of Claim 10 wherein said sacrificial collar comprises a layer of nitride.

[c14] The method of Claim 13 wherein said sacrificial collar further comprises a layer of oxide contacting said widened sidewalls under said layer of nitride.

[c15] The method of Claim 10 further comprising widening said lower portion by an isotropic etch to achieve a bottle-shaped structure prior to forming said capacitor.

[c16] The method of Claim 10 further comprising widening

said opening in said pad stack selective to said hard-mask prior to vertically deepening said trench such that said sidewalls of said hardmask overhang said sacrificial collar and protect said sacrificial collar while deepening said trench.

[c17] The method of Claim 16 wherein said opening in said pad stack is widened at the same time that said sidewalls of said trench are horizontally widened.

[c18] An integrated circuit including a deep trench structure formed in a single-crystal region of a semiconductor substrate, the deep trench structure comprising:
an upper trench portion formed in said single-crystal region, said upper trench portion having an opening of rectangular shape; and
a lower trench portion formed in said single-crystal region below said upper trench portion.

[c19] The integrated circuit of claim 18 wherein said upper trench portion is widened relative to said lower trench portion.

[c20] The integrated circuit of claim 18 wherein said lower trench portion has a bottle shape.